Experimental Butchery Study Investigating the Influence of Timing of Access and Butcher Expertise on Cut Mark Variables

Journal:	*International Journal of Osteoarchaeology*
Manuscript ID	OA-17-0086.R2
Wiley - Manuscript type:	Research Article
Date Submitted by the Author:	n/a
Complete List of Authors:	Pobiner, Briana; Smithsonian Institution, Anthropology Higson, Charles; Durham University, Anthropology Kovarovic, Kris; Durham University, Anthropology Kaplan, Robert; Montgomery College - Germantown Campus, Anthropology Rogers, Jacklyn; Dickinson College, Anthropology Schindler, William; Washington College, The Eastern Shore Food Lab
Keywords:	hominin, butchery, carcass, cut mark, actualistic, Plio-Pleistocene, tool stroke, butcher expertise

Experimental Butchery Study Investigating the Influence of Timing of Access and Butcher Expertise on Cut Mark Variables

Briana L. Pobiner[1], Charles P. Higson[2], Kris Kovarovic[2], R. S. Kaplan[3], Jacklyn Rogers[4], & William Schindler[5]

[1] Human Origins Program, National Museum of Natural History, Smithsonian Institution, 10th Street & Constitution Avenue NW, Washington DC 20012-0112, USA

[2] Department of Anthropology, Durham University, South Road, Durham DH1 3LE, United Kingdom

[3] Department of Education and Social Sciences, Montgomery College, 20200 Observation Drive, Germantown, MD 20876

[4] Department of Archaeology, Dickinson College, 28 North College Street, Carlisle, PA, 17013, USA

[5] The Eastern Shore Food Lab, Washington College, 300 Washington Ave, Chestertown, MD 21623 USA

Corresponding Author:
Briana L. Pobiner
Human Origins Program, National Museum of Natural History, Smithsonian Institution, 10th Street & Constitution Avenue NW, Washington DC 20012-0112, USA Tel: +1 202 633 1985
Fax: +1 202 357 2208

Author email addresses:
pobinerb@si.edu
higsoncp@gmail.com
kris.kovarovic@durham.ac.uk
rogersjacklynj@gmail.com
rskaplan88@gmail.com
wschindler2@washcoll.edu

Running Title: Effect of Timing of Access and Butcher Expertise on Cut Marks

Key Words: hominin, butchery, carcass, cut marks, actualistic study, Plio-Pleistocene, tool strokes, butcher expertise

Abstract:

Cut marks on fossils from Plio-Pleistocene faunal assemblages can elucidate the timing and nature of hominin procurement of animal tissues. While butchery experiments have great potential to enhance our ability to understand hominin butchery behaviors, studies that model variation in the timing of access to carcasses and butcher expertise have either yielded conflicting results or have not yet been investigated. We conducted butchery experiments on 8 pig limbs with replicated Oldowan flake tools that varied the amount of flesh removed prior to butchery (simulating early or late carcass access) and butcher expertise. These experiments investigated the effects of these variables on resultant cut mark count, length, and number of tool strokes. The relationship between the number of tool strokes as a measure of butchery intensity and the number of cut marks produced was also explored. We also compared the length of experimental cut marks to those on 1.5 million year old fossil bones from Koobi Fora, Kenya. While the bones that were partially defleshed prior to butchery had a higher number and longer cut marks on average than fleshed bones, and the expert butcher created fewer and shorter cut marks than the novice butcher, none of these relationships were statistically significant. We found no relationship between the number of tool strokes and the amount of flesh removed prior to butchery or the number of cut marks produced during butchery, although the expert butcher used fewer tool strokes. While not statistically significant, the length of cut marks created by the novice butcher is much more variable than those created by the expert butcher and the fossil cut marks, and fossil cut marks are much shorter than those created by both modern butchers. More work needs to be undertaken to identify cut mark attributes that may be influenced by behavioral or ecological variables that can be measured and manipulated during butchery experiments.

Introduction

Studies of butchery-marked faunal assemblages from African Plio-Pleistocene sites have provided insight into the carcass acquisition and processing practices of the earliest meat and marrow eating hominins. Evidence for at least occasional hominin butchery of larger mammal carcasses dates back to at least 2.5-2.6 Ma at Gona and Bouri, Ethiopia (de Heinzelin et al., 1999; Domínguez-Rodrigo et al., 2005), and possibly to 3.4 Ma at Dikika (McPherron et al*.,* 2010; Thompson et al, 2015). Butchery marks become more common in faunas between 2.0-1.5 Ma; for example, at Kanjera South, Kenya (2.0 Ma - Ferraro et al., 2013); Koobi Fora, East Turkana (1.95 Ma - Braun et al., 2010 and 1.5 Ma – Pobiner et al. 2008) and Olduvai Gorge (1.8 Ma - Bunn 1981; Potts and Shipman, 1981; Bunn and Kroll, 1986; Blumenschine, 1995; Domínguez-Rodrigo et al. 2007). Evidence from Kanjera South in the form of multiple sedimentary layers with butchery marked bones indicates that hominins repeatedly visited the same location on the landscape to conduct butchery activities over time, suggesting that this dietary behavior was persistent in hominins by 2.0 Ma (Ferraro et al., 2013).

Presently, there is little to no consensus regarding the behavioral ecology of Plio-Pleistocene hominin acquisition and processing of medium to large animal carcasses, and what amounts and types of resources hominins acquired from those carcasses. Questions about whether hominins - particularly earlier species of *Homo* - engaged in hunting or scavenging to acquire animal tissues (such as meat, marrow, and organs) and the timing of hominin access to various carcass resources have been debated using taphonomic data for several decades (e.g. Blumenschine, 1987, 1995; Selvaggio, 1998., Speth, 1989; Blumenschine and Cavallo, 1992; Domínguez-Rodrigo, 1997; Domínguez-Rodrigo and Pickering, 2003; Pobiner et al., 2008, 2015; Pante et al., 2012; Ferraro et al., 2013; Pobiner, 2015). More broadly, the timing of access (early or late), mode of acquisition (hunting or various forms of scavenging), frequency of meat and marrow acquisition, and amount of meat and marrow acquired during carcass processing are all variables that are extremely pertinent to understanding the ecological niche inhabited by different species of hominins in the Pliocene and Pleistocene, especially as hominins increasingly invaded the larger predator guild (Brantingham, 1998). Some of these dietary behavioral variables are likely more visible in the archaeological record than others. We might not expect to see a single, uniform signal or pattern of these variables in the archaeological record as hominin behavior could be expected to be flexible according to local ecological conditions such as habitat distribution and heterogeneity, seasonality, predator species and density, and carcass encounter rate and completeness (e.g. Pobiner, 2015; Merritt, 2017).

Increasingly, experimental butchery studies are working towards identifying some of the variables that we may be able to reliably use to infer hominin butchery behavior from fossil assemblages (e.g. Blumenschine, 1987; Selvaggio, 1994; Capaldo, 1998; Domínguez-Rodrigo, 1997; Egeland, 2003; Pobiner and Braun, 2005a; Merritt, 2015; Soulier and Costamagno, 2017). These studies manipulate variables related to the processing of animal tissues using stone tools (such as the number of tool strokes) and examine the resultant butchery traces (such as the number of cut marks).Varying hypotheses of the relationship between cut mark patterning (mainly number and location) and the amount of meat present on carcasses prior to processing – as a proxy for hominin timing of access to carcasses – have been proposed. For example, Binford (1986) suggested that numerous cut marks indicate scrap defleshing or secondary access to meat, while Bunn (Bunn et al. 1986; Bunn, 2001) suggested that a high number of cut marks represents the removal of substantial quantities of meat and thus primary access. Yet a consistent relationship between cut mark count and pre-butchery flesh quantity has not been found in butchery experiments (Lupo and O'Connell, 2002; Pobiner and Braun, 2005b). A recent experimental butchery study which included an investigation of cut mark length predicted that defleshing muscle scraps would produce clusters of short, closely spaced cut marks due to scraps being slippery and difficult to slice , but found that bulk muscle removal and scrap defleshing was not correlated with median or standard deviation of cut mark length (Merritt, 2016). Additionally, despite suggestions of a correlation between butchering effort or "intensity" and cut mark count (Milo, 1998, Abe et al., 2002), no relationship has been found between cut mark count and the number of tool strokes employed (Egeland, 2003). However, Merritt (2017) found that different butchery actions (skinning, defleshing, and disarticulation) are differentially distributed across the skeleton and can leave distinct, interpretable cut marks on the skeleton. This experimental butchery study found that fragmentation introduces a bias for detecting

butchery traces of early carcass access due to a higher number of cut marks resulting from defleshing, which were most often found on dense midshaft portions that tended to survive density-mediated destruction. This pattern was different from that found in cut marks resulting from disarticulation, which were rare and mainly found on epiphyseal portions - portions often deleted by density mediated destruction (Merritt, 2017). This result suggests that certain parts of the skeleton (in this case, the elbow joint) have strong promise to offer a clearer view of different stages of carcass consumption behaviors than previous analytical methods offered.

The question of how butcher expertise may influence cut mark variables is a potentially useful line of inquiry for experimental butchery studies, but has not been formally experimentally investigated. Lyman (1995) suggests that in general, proficient butchers would purposefully avoid making contact with bones during butchery to avoid damaging the edges of their tools. Padilla (2008) found that as modern butchers increased their butchery experience they created fewer cut marks during butcheries, decreased the amount of time it took to conduct butcheries, and used their hands more and tools less to remove the flesh – increasing the use-life of tools. Similarly, Domínguez-Rodrigo (1997) anecdotally reported that as his butchery skills increased the number of cut marks in some of his butchery experiments decreased. Bunn and Kroll (1986) asserted that Hadza hunters were able to process animal carcasses without imparting unwanted cut marks on the bones (Lupo, 2012) and Crader (1983) observed a similar pattern in elephant butchery by the Bisa. Frison (1986) and Haynes (1993) describe modern elephant cull sites in Hwange National Park with experienced butchers as devoid of cut marks, and Haynes (1993) noted that during his own experience butchering over 40 elephants, thick articular cartilage on the limbs prevented even what at first appeared to be deep knife marks from being preserved on the cortical bone. However, Haynes and Krasinski (2010) noted that the less experienced butchers did produce cut marks on elephant bones, and in some instances the large size and amount of meat on the animals is likely responsible for the lack of cut marks. While the enormous amount of meat on elephants or other proboscideans may be a special case that drives a paucity of cut marks created during defleshing of these animals, these examples are included here as they are relevant to a possible relationship between butcher expertise and cut mark count.

Archaeologically, Stiner et al. (2011) observed that cut marks on assemblages from Qesem Cave in Israel (400-200 Ka) were more abundant and less randomly oriented than later (Middle and Upper Paleolithic) sites in the Levant. They interpreted this to mean that that a higher number and/or less experienced butchers were involved in the processing of fallow deer at Qesem Cave rather than a single or a few skilled butchers (as in modern human groups) which they suggest would result in orderly, fairly well-aligned cut marks. Yet Egeland et al. (2014)'s butchery experiments found that cutmark angle did not differ significantly between carcass parts butchered by a single versus multiple novice butchers. In his modern butchery experiments, Merritt (2016) found that experimentally produced cut marks were generally longer and had a larger standard deviation than cut marks from an Early Stone Age site in Koobi Fora, Kenya. In sum, there is currently a lack of clear relationship in patterning of many measurable archaeological cut mark variables (such as number, location, angle, and length) and behavioral or ecological contexts of butchery we would like to be able infer from these variables. These behavioral or ecological contexts include the amount

of meat present at the initiation of butchery, butcher expertise, and number of butchers.

Here we present results from an experiment that varied the amount of flesh present on ungulate limbs prior to butchery and butcher expertise, two variables of potential interest in butchery studies. We investigated whether these two variables were related to the number (Pobiner and Braun, 2005b) and length (Merritt, 2015) of cut marks present on the bones after butchery. We also investigated whether the number of tool strokes that occurred during butchery was related to the number and length of cut marks (Egeland, 2003). We used pre-processing flesh quantity on a carcass as a proxy for the timing of hominin access to animal carcasses, where fully fleshed represents early access - implying that hominins were the initial carcass consumer and had access to a complete carcass - and partially defleshed represents late access - implying that hominins were a secondary carcass consumer and had access to a partially defleshed carcass. Finally, we compared the length of the experimentally produced cut marks on ungulate limb bones to those on a sample of ~1.5 million fossils from Koobi Fora, Kenya to determine whether the length of the fossil cut marks were more similar to those created by the novice or expert butcher.

The experimental butchery study addresses the following hypotheses (see Table 1 for hypothetical predictions).

Hypothesis 1: The amount of flesh present on the carcass prior to butchery influences the number of tool strokes used and the number and length of cut marks produced during butchery.

Hypothesis 2: The butcher's level of expertise influences the number of tool strokes used and the number and length of cut marks produced during butchery.

Hypothesis 3: The number of cut marks produced is correlated with the number of tool strokes during butchery.

<Table 1 about here>

Materials and Methods

We conducted experimental butcheries on 8 limbs of two young adult domestic pigs (*Sus domesticus*), with most limb epiphyses that were in the process of fusing but not yet completely fused, categorized as Size 2 individuals (50-250 lbs: Bunn, 1982). Suids of this size class and larger are commonly found in faunal assemblages at palaeoanthropological sites (Bunn, 1982; Harris and Cerling, 2002; Blumenschine and Pobiner, 2007; Ungar, 2007; Pobiner et al., 2008). As the size of an animal may influence the number of cut marks inflicted during butchery, with at least one study documenting a positive correlation between animal size and cut mark frequency (Pobiner and Braun, 2005b) and another documenting a positive correlation between animal size and cut mark length (Merritt 2016), we chose to keep the animal size and species constant as to not introduce additional variables into the butchery experiment. The carcasses were obtained from a commercial butcher in Maryland, USA. Processing was performed on 'supple' ('fresh' and 'easily manipulated') forelimbs and hindlimbs (Egeland, 2003). Only long bones were included for these experiments,

as most models of hominin carcass exploitation are based on long bones due to their abundance in the fossil record and likelihood of them preserving bone surface modifications related to butchery activities (e.g. Bunn and Kroll, 1986; Domínguez-Rodrigo et al., 2009).

One of the primary variables manipulated in this experiment was pre-butchery flesh quantity. Two categories of pre-butchery flesh quantity were used: fully fleshed limbs and partially defleshed limbs. In both cases, fully fleshed limbs (including the scapula in the case of forelimbs) were first carefully disarticulated from the main carcass to ensure no cut marks were inflicted on the bones. Limbs were weighed, and only the limbs that were partially defleshed for this study had 50% of their total mass removed by a professional butcher using metal knives. As the initial limb weight includes all meat and bones, including metapodials and phalanges which were not defleshed for this experiment, removing 50% of this weight actually removed more than half of the total amount of meat present on each limb. No marks were inflicted on the bones during this preparatory defleshing process, in which flesh was removed predominantly, but not exclusively, from the upper limb bones (femur and humerus) in order to simulate the large felid carnivore carcass consumption patterns observed by Blumenschine (1986), Pobiner (2007), and Domínguez-Rodrigo (1999). The shafts of the limb bones were not exposed during the preparatory defleshing process, which focused on removing easily detachable larger muscle masses and did not involve any scrap defleshing.

The second variable manipulated was the expertise of the butcher. The experiment consisted of one novice butcher with no butchery expertise (CH), who had never butchered an animal before, and one expert butcher with ample butchery experience (WS). To elaborate, WS has been butchering wild game for 34 years and domesticated animals for 10 years; he learned how to butcher from hunters, professional butchers, through ethnographic work across the world, and through professional training in butchering, charcuteries, and salumi at the Italian Culinary Institute. Both butchers used simple Oldowan flakes made of argillite and Dover flint to process four limbs each during a single butchery episode lasting a few hours. The butchers were cognizant of the purpose of the experiment but received no instructions except to remove as much meat from the limbs as possible, and there was no time limit imposed. Butchers chose tools from a selection of flakes of similar sizes and were allowed to use as many as necessary. To avoid any influence on the novice's butchery method, the expert performed the butchery in a separate location. Each butcher processed two fully fleshed and two partially defleshed limbs. Four categories of butcher expertise and pre-processing meat quantity were used, with 2 limbs in each category: Expert Butcher/Defleshed (ExDefl) - one right forelimb and one left hindlimb, Novice Butcher/Defleshed (NovDefl) - one left forelimb and one right hindlimb, Expert Butcher/Fleshed (ExFl) - one left forelimb and one right hindlimb, and Novice Butcher/Fleshed (NovFl) - one right forelimb and one left hindlimb. Figure 1 shows the right forelimb butchered by the novice, as an example of how much flesh was removed during the butchery. The number of tool strokes was recorded by an independent observer using a tally hand counter. A single stroke was defined as a distinct slicing motion that went in one direction followed by a pause (following Egeland 2003).

<Figure 1 about here>

After the butchery trials, bones were boiled and remaining flesh was removed using wooden tools in order to avoid leaving unintentional marks. Bones were examined for cut marks using oblique light and a 10x magnification lens (Blumenschine et al., 1996). The length of each individual cut mark from the total sample of 105 experimentally produced cut marks was recorded to the nearest .01 millimeter using digital calipers (Table 2). For cut marks with slightly curved trajectories, the marks were measured from the initiation of the cut mark on one end to the termination on the other end. None of the marks were long enough to substantively wrap around the axis of the bone, thus making a very long mark seem shorter because of the use of calipers to measure them.

<Table 2 about here>

The fossil sample consists of measurements of cut marks on mammal (mainly ungulate) bones from animals in size classes 2 (50-250 lbs) and 3 (250-750 lbs) following Bunn (1982) from three ~1.5 million year old zooarcheological assemblages from the Okote Member at Koobi Fora, Kenya: FwJj14A, FwJj14B, and GaJi14A (see Pobiner et al., 2008 and Merritt, 2017 for more details about the fossil sites). These cut and percussion marked fossils have been interpreted as evidence for hominin defleshing, disarticulation, and marrow extraction during carcass processing (Pobiner et al., 2008; Merritt, 2017). This fossil sample was chosen because of the senior author's previous in-depth analysis of the assemblage, because the fossils exhibit generally quite good surface preservation, because it has one of the highest numbers of butchery marks of any Early Stone Age zooarchaeological assemblage (>200 butchery marked fossils) (Pobiner et al., 2008), and because we felt that there would be a large enough sample size of cut marks on appropriately sized animal fossils for comparison to the experimental butchery sample. It is also one of the only Early Stone Age zooarchaeological assemblages that has been interpreted as representing primary and secondary access to larger animal carcasses (Merritt, 2007).

The length of each individual cut mark from the total sample of 134 cut marks on 28 fossils was recorded to the nearest .01 millimeter using digital calipers in the same manner as the modern cut marks (Table 3). The fossil cut marks were selected from a larger sample of nearly 300 cut marked fossils; we specifically chose fossils identified only to size 2 or 3 animals, and chose cut marks only on midshaft and near epiphyses, for maximum comparability with the experimental cut marks.

<Table 3 about here>

We recorded two independent variables: pre-butchery flesh quantity and butcher expertise. A Shapiro-Wilk test for normality indicates that the data for average cut mark length, number of cut marks, and number of tool stroked are not normally distributed, likely due to small sample size (Average cut mark length: W=0.93, P=0.53; Number of cut marks: W=0.95, P=0.75; Number of tool strokes W=0.93, P=0.55). We therefore used a Mann-Whitney two-sample rank-sum test, a nonparametric test, to determine whether the distributions of measurements or counts of these variables within each of the two groups (expert vs. novice butcher and fleshed vs. defleshed limbs) differed significantly**.** All statistical tests were conducted in R statistical software (R Core Team 2013). Please contact the authors for a copy of

the R code. A one-way between subjects ANOVA was conducted to compare the effect of butcher experience on cut mark length in the experimental and archaeological samples.

Results

Summary

A total of 105 cut marks were observed and measured on 17 of the 24 bones involved in the butchery trials (Table 2, Figure 2). Seven bones that had meat removed prior to butchery (bones in the defleshed sample) exhibited cut marks (ExFl = 24 marks, NovFl = 18 marks) and 10 bones that were fully fleshed prior to butchery exhibited cut marks (ExDef = 26 marks, NovDefl = 37 marks) (Table 2). The maximum number of cut marks recorded on any bone was 18, which was the number of marks recorded on both humeri butchered by the novice butcher. Seven bones had no cutmarks: two defleshed radii, two defleshed ulnae, one fleshed radius, one fleshed ulna, and one fleshed femur. Individual cut mark lengths ranged from 1.4 mm to 29.96 mm across the entire sample with an overall mean of 8.31 (SD=3.91).

<Figure 2 about here>

A total of 134 cut marks were observed and measured on the Koobi Fora fossil assemblages (Table 3). We compared cut mark length but not cut mark count between the modern and fossil cut marks, as the fossils were all incomplete bones and usually quite fragmentary. The difference of several orders of magnitude in the surface area of the modern and fossil bones means that the fossils are more likely to have fewer cut marks per fragment, as the number of bone surface modifications has been shown to be related to the size of a bone fragment (Faith 2007). Because of this taphonomic difference in the modern and fossil assemblages, we did not compare the number of cut marks on complete bones from the butchery experiments to the number of cut marks on fragmentary bones from the fossil assemblages as we think this comparison would not be behaviorally meaningful.

Pre-butchery flesh quantity (Hypothesis 1)

Average cut mark length on bones from defleshed limbs was shorter (7.24 mm) than average cut mark length on bones from fully fleshed limbs (9.06 mm), supporting our prediction (Table 4). However there were more cut marks on bones from fleshed limbs (56) than defleshed limbs (49), which did not support our predictions (Table 4). Moreover we did not find a statistically significant relationship between the amount of meat present on a bone before butchery and either cut mark count (the total number of marks for all defleshed or fleshed trials) or average cut mark length (Table 5).

<Table 4 about here>

<Table 5 about here>

Butcher expertise (Hypothesis 2)

Compared with the novice butcher, the expert butcher created fewer cut marks (50 vs. 55), shorter cut marks (average 7.97 mm vs. 8.69 mm), and used fewer tool strokes (2797 vs. 3187), all supporting our predictions (Table 4). However we did not find a statistically significant relationship between butcher expertise and cut mark count or average cut mark length (Table 5). While there was a fairly large difference in the range of cut mark length, this is likely due to small sample size. A t-test comparing the mean lengths of cut marks created by the expert and novice butcher did not find a statistical difference (t=0.4292, df=3.542, p=.6925).

Number of tool strokes (Hypothesis 3)

The number of tool strokes varied between 522 and 940 for individual processing events on single limbs. We found no significant relationship between the number of tool strokes and the number of cut marks produced on each limb (r=-0.198, p=0.639). We also found no relationship between pre-butchery flesh quantity and the number of tool strokes (r=-0.750, p=0.860) or between butcher expertise and the number of tool strokes (r=0.343, p=0.405). Additionally, we found no significant relationship between the amount of time it took to butcher each limb and the number of cut marks (r=-0.2354, p= 0.5746) or the average cut mark length (r= -0.2023, p= 0.6308). However, we found a strong and significant positive relationship between the amount of time it took to butcher each limb and tool stroke count (r=.7089, p= .0489).

Fossil cut marks

There is a significant difference in cut mark length between the novice, expert and fossil samples [$F(2,33)=27.18$, $p<0.005$] (Figure 3). Post hoc comparisons using Tukey HSD test indicate that statistically significant difference is met between fossil and expert cut mark length (p adjust < 0.005) and fossil and novice cut mark length (p adjust < 0.005). However, there is not a statistically significant difference between the novice and expert cut mark lengths (p adjust = 0.773). Taken together, these results suggest the cut marks created by novice and expert butchers do not vary significantly in their mean cut mark length. However, both experimental groups do vary significantly from the fossil data in mean cut mark length, with the fossil cut marks being shorter than the experimental cut marks. Additionally, cut marks created by the novice butcher are more variable in length than cut marks in both the expert and fossil samples (here CV = coefficient of variation: fossil-expert CV=-5.223; novice-expert CV=-0.795; novice-fossil CV=4.428).

<Figure 3 about here>

Discussion

While many of our predictions were supported by the data collected from the butchery experiment, we did not find statistically significant correlations among any of the variables we investigated. The lack of correlation between pre-butchery flesh quantity and cut mark number or length concurs with studies that have found the meat quantity on a carcass to be unrelated to cut mark number (Lupo and O'Connell, 2002; Pobiner and Braun, 2005b; Merritt, 2016), but contrasts with assertions that variability in cut mark number would be strongly indicative of either a lesser (Binford 1981; 1986) or greater (Bunn and Kroll 1986) pre-butchery flesh quantity. Our data also do not

support predictions or data collected on previous observations of modern butchery that more experienced butchers would leave fewer butchery marks (Lyman, 1995; Domínguez-Rodrigo, 1997; Padilla, 2008; Haynes and Krasinski, 2010).

The length of cut marks has received little theoretical or experimental focus (but see Merritt, 2016 and Soulier and Morin, 2016). While cut mark length was not statistically correlated with the amount of pre-butchery flesh quantity or butcher expertise in this study, cut marks on the partially defleshed limbs were on average shorter than those in the fully fleshed limbs (7.24 mm and 9.06 mm, respectively). Cut marks on the ~1.5 million year old fossil assemblages from Koobi Fora were shorter than those created by both the novice and expert experimental butchers. This accords with Merritt's (2016) recent finding that cut marks on fossils from the same assemblages Koobi Fora were shorter than his experimentally produced cut marks. While we are unable to do a specimen-by-specimen comparison of the cut marked fossils to see if we were using the exact same fossil sample as Merritt (2016) did not publish his list of specimens, our samples are from the same fossil assemblages, so it is likely that many of our cut marks are from the same fossil specimens. Merritt (2016) also found that experimentally produced cut marks had a larger standard deviation in length than the fossil cut marks; we found the same pattern with the experimentally produced cut marks made by the novice butcher, but not the cut marks experimentally produced by the expert butcher. We might have predicted the opposite pattern, though, since the experimental butcher in Merritt's study was an expert (a Dassanech man from northern Kenya experienced in livestock butchery).

Recently, Soulier and Morin (2016) found that cut marks on long bones from both experimental and zooarchaeological assemblages (27 Middle and Upper Paleolithic sites from France) are generally longer when longitudinally oriented than when obliquely or transversely oriented. They also found that in the archaeological samples, cut marks were longer on upper limb bones (humerus and femur) than intermediate limb bones (radio-ulna and tibia), and that the number of transverse cut marks decreased and the number of longitudinal cut marks increased through time, regardless of skeletal element or species. Additionally, Merritt (2016) found that cut mark length and standard deviation of length is related to animal size: in his butchery experiments clusters of cut marks on cow bones tended to have greater area, longer median length, and greater deviation of mark length than those on goat bones. We explored whether the number or length of cut marks in our experimental samples varied by skeletal element by first using ANOVA tests for differences among sample means followed by a post-hoc Tukey's HSD (Table 6) to determine which skeletal element(s) was driving the statistically significant ANOVA result for cut mark number. We found a statistically significant difference between means of cut mark numbes on different skeletal elements as determined by ANOVA ($F(4,12) = 5.318$, $p = 0.011$), with the humerus having more cut marks than any of the other skeletal elements (Table 6), there was no difference between the mean lengths of cut marks on any of the skeletal elements as determined by ANOVA (($F(4,12) = 1.128$, $p = 0.389$).

Given that few studies have investigated cut mark length, especially in relationship to butcher expertise, there is still potential for future studies to investigate cut mark length as an indicator of butchery behavior particularly with larger sample sizes. We acknowledge that this butchery experiment included a small sample size of only 8 limbs (due to the time constraints for undertaking the butchery), which is not ideal. A

larger sample size would increase the power of statistical tests. Future studies could also explore whether cut mark length varies by skeletal element or specific anatomical regions (e.g. upper limb bones versus intermediate limb bones). Anatomical factors such as the attachment sites and sizes of muscles processed during butchery, which are related to animal size and species, most likely influence transport and processing decisions and the resulting skeletal traces such as skeletal element profiles and cut mark number and distribution.

<Table 6 about here>

In this experiment, the number of tool strokes as a measure of butchery intensity was positively correlated with the amount of time each butchery event took, yet the number of tool strokes was not correlated with the number of cut marks inflicted during butchery. This result accords with Egeland (2003) and suggests that the number of tool strokes is not a measure of butchery intensity that we can trace in the archaeological record with cut mark counts. The number of tool strokes was also not correlated with pre-butchery flesh quantity or butcher expertise.

The results obtained by this study provide some insights into the nature of hominin butchery in the past. In this experiment, pre-butchery flesh quantity was manipulated to represent primary or secondary access to carcasses by hominins. Substantial amounts of flesh can be acquired via hunting, power or confrontational scavenging, or certain opportunistic scavenging circumstances (e.g. Capaldo and Peters 1995; Pobiner 2015); in each case a near fully fleshed carcass is assumed to be available for butchery. Secondary access is assumed to reflect passive scavenging. While this experiment used a uniform 50% total limb weight reduction of meat on each limb to model secondary access to a carcass, the condition of carcasses can vary greatly after carnivore consumption – both in terms of meat yield and destruction patterns. Observations of wild carnivores indicate that they can consume between very little and up to 80% of carcass flesh before abandonment (Blumenschine, 1986; Domínguez-Rodrigo, 1997; Selvaggio, 1998; Pobiner, 2007, 2015). With this in mind, future actualistic studies exploring the impact of pre-butchery meat quantity could use a greater variation in the amount of flesh removed prior to butchery. Additionally, future studies could also include different sized animals and different taxa.

This study included two stone tool raw materials, argillite and flint, which have different grain sizes and levels of hardness and uniformity which could affect butchery activity and cut mark patterning. Argillite is a nonfissile mudrock that is very highly indurated, perhaps weakly metamorphosed, and lacking slaty clevage (Blatt 1982) generally made up of clay sized particles (less than 60 micrometers) that were first lithified through sedimentary processes and then partially metamorphosed. Stone tools made from argillite have edges that are typically more friable and not as durable, and the somewhat porous nature of the argillite seems to attract grease/fat/lipids and impacts both the manner in which it cuts and how easily it is held in the hand. In other words, as butchering progresses, argillite flakes seems to become duller and more difficult to hold - but wiping or washing them off remedies this issue. Flint, on the other hand, is a harder crypto-crystalline silica rock made up of microscopic crystals of silica between 0.5 to 20 micrometers (Knauth, 1994). In his raw material ranking system based on replication experiments, Callahan (1979) suggests that flints are easier to “work” than argillite (see Braun et al., 2009 for more

extensive discussion of stone tool raw material qualities based on physical properties). While this study does not focus on the effect of raw material on cut mark morphology (e.g. Greenfield, 2006; Braun et al., 2016; Maté-González, 2017), recent studies have found that the hardness of tool edges can affect cut mark morphology (Braun et al., 2016). Turning to the archaeological record, Braun et al (2009) found that hominins at Kanjera South, Kenya were selecting raw materials to make Oldowan tools based on their durability (the ability of an edge to resist degradation by a static or dynamic force) rather than their fracture predictability (the consistency with which a particular type of stone fractures), and Stout et al (2004) found that hominins at Gona preferred finer-grained, phenocryst-poor materials for Oldowan toolmaking. Clearly, even the earliest stone tool using hominins had some knowledge of raw material properties and selected raw materials based on specific characteristics. Differences in raw material properties could lead butchers to use different amounts of force, different numbers and types of cutting actions, different rates of tool cleaning or resharpening, and/or change other behavioral variables which could potentially affect butchery activity and resultant cut mark patterning. These stone tool raw material variables warrant further exploration in future experimental butchery studies.

Conclusion

This study found no statistically significant relationship between either the amount of meat present on bones prior to butchery, or butcher expertise, and cut mark number or cut mark length, although bones that were fully fleshed prior to butchery had a lower number and shorter cut marks on average than partially defleshed and the novice butcher created a higher number and longer cut marks than the expert butcher. We also found no relationship between the number of tool strokes and the pre-butchery flesh quantity, butcher expertise, and cut mark number, although the novice butcher used more tool strokes and there was a slightly positive correlation between number of tool strokes and cut mark count. Finally, we found that cut marks on 1.5 million year old fossils were shorter than those created by both the expert and the novice modern butchers.

The question of the amount of meat acquired by hominins under various ecological conditions remains pertinent to the overall understanding of early human dietary behavior. Given that multiple carcass acquisition strategies can result in a high meat yield (e.g. hunting and power scavenging), it may not be possible to distinguish between these behaviors based solely on cut mark patterns; additional contextual taphonomic data such as skeletal part profiles and carnivore damage patterns are also undoubtedly important. Additionally, it is possible that no single strategy characterized hominin carcass acquisition and processing activity and that Early Stone Age zooarchaeological sites are most often palimpsests of hominin and carnivore processing and consumption (e.g. Egeland et al, 2004). Yet opportunity remains for experimental butchery studies to identify links between cut marks left on faunal remains and the behavioral and ecological contexts under which those cut marks were inflicted. For instance, Merritt (2017) recently introduced a new analytical method to distinguish between defleshing and disarticulation cut marks on the elbow joint that allows inference of early or late access by hominins to carcass resources based on experimental butchery. Future studies should, whenever possible, include analytical scales ranging from individual specimens to entire assemblages.

Acknowledgements

Many thanks for Steve Merritt for his advice and review of this article, as well as the thorough, thoughful, and constructive reviews of two other anonymous reviewers. This research was funded by a Durham University Department of Anthropology postgraduate bursary (CH) and a Durham University Learning and Teaching Award (KK). The authors declare that they have no conflict of interest.

References

Abe Y, Marean CW, Nillsen PJ, Assefa Z, Stone EC. 2002. Analysis of cutmarks on archaeofauna: a review and critique of quantification procedures, and a new image-analysis GIS approach. *American Antiquity* **67**: 643-663.

Binford LR. 1981. Bones: Ancient Men and Modern Myths. Academic Press: Orlando.

Binford LR. 1986. An Alyawara Day: Making Men's Knives and beyond. *American Antiquity* **51**: 547-562.

Blatt H. 1982. Sedimentary petrology. W.H. Freeman and Company, San Francisco.

Blumenschine RJ. 1986. Carcass consumption sequences and the archaeological distinction of scavenging and hunting. *Journal of Human Evolution* **15**: 639-659.

Blumenschine RJ. 1987. Characteristics of early hominid scavenging niche. *Current Anthropology* **28**: 382-407.

Blumenschine RJ, Pobiner BL. 2007. Zooarchaeology and the Ecology of Oldowan hominin carnivory. In *Evolution of the Human diet*, Ungar PS (ed.). Oxford University Press: Oxford; 167-190.

Blumenschine RJ. 1995. Percussion marks, tooth marks, and experimental determinations of the timing of hominid and carnivore access to long bones at FLK Zinjanthropus, Olduvai Gorge, Tanzania. *Journal of Human Evolution* **29**: 21–51.

Blumenschine RJ, Cavallo JA. 1992. Scavenging and human evolution. *Scientific American* **267**: 90-96.

Blumenschine RJ, Marean CW, Capaldo SD. 1996. Blind tests of inter-analyst correspondence and accuracy in the identification of cut marks, percussion marks, and carnivore tooth marks on bone surfaces. *Journal of Archaeological Science* **23**: 493-507.

Brantingham PJ, 1998. Hominid–Carnivore coevolution and invasion of the predatory guild. *Journal of Anthropological Archaeology* **17**L 327–353.

Braun DR., Plummer T, Ferraro JV, Ditchfield P, Bishop LC. 2009. Raw material quality and Oldowan hominin toolstone preferences: evidence from Kanjera South, Kenya. *Journal of Archaeological Science* **36**: 1605-1614.

Braun DR, Harris JWK, Naomi EL, McCoy JT, Herries AIR, Bamford MK, Bishop LC, Richmond BG, Kibunjia M. 2010. Early Hominin diet included diverse terrestrial and aquatic mammals 1.95 Ma in East Turkana, Kenya. *Proceedings of the National Academy of Sciences* **107**: 10002-10007.

Bunn HT. 1981. Archaeological evidence for meat-eating by Plio-Pleistocene hominids from Koobi Fora and Olduvai Gorge. *Nature* **291**: 574–577.

Bunn HT. 1982 Meat-eating and human evolution: studies on the diet and subsistence patterns of Plio-Pleistocene hominids in East Africa. PhD dissertation, Department of Anthropology, University of California, Berkeley.

Bunn HT. 2001. Hunting, power scavenging, and butchering by Hadza foragers and by Plio-Pleistocene Homo. In *Meat-eating and Human Evolution*, Stanford C, Bunn HT (eds.). Oxford University Press: Oxford; 199-218.

Bunn HT, Kroll EM. 1986. Systematic butchery by Plio/Pleistocene Hominids at Olduvai Gorge, Tanzania. *Current Anthropology* **27**: 431-452.

Callahan E. 1979. The basics of biface knapping in the eastern fluted point tradition. A manual for flintknappers and lithic analysts. Archaeology of Eastern North America 7.

Capaldo SD. 1998. Simulating the formation of dual-patterned archaeofaunal assemblages with experimental control samples. *Journal of Archaeological Science* **25**: 311-330.

Capaldo SD, Peters CR. 1995. Skeletal inventories from wildebeest drownings at Lakes Masek and Ndutu in the Serengeti ecosystem of Tanzania. *Journal of Archaeological Science* **22**: 385-408.

Crader DC. 1983. Recent single-Carcass Bone Scatters and the probability of 'butchery' sites in the archaeological record. In *Animals and Archaeology, Volume 1*: *Hunters and Their Prey*, Clutton-Brock J, Grigson C (ed.). British Archaeological Reports: Oxford **163**: 107-141.

de Heinzelin J, Clark JD, White T, Hart W, Renne P, WoldeGabriel G, Beyene Y, Vrba E. 1999. Environment and behavior of 2.5 million-year-old Bouri hominids. *Science* **284**: 625–629. DOI:10.1126/science.284.5414.625.

Domínguez-Rodrigo M, Mabulla AZP, Bunn HT, Barba R, Diez-Martin F, Egeland C. 2009. Unraveling hominin behavior at another anthropogenic site from Olduvai Gorge (Tanzania): new archaeological and taphonomic research at BK, Upper Bed II. *Journal of Human Evolution* **57**: 260-283.

Domínguez-Rodrigo M. 1997. Meat-eating by early hominids at the FLK 22 *Zinjanthropus* site, Olduvai Gorge (Tanzania): an experimental approach using cutmark data. *Journal of Human Evolution* **33**: 669-690.

Domínguez-Rodrigo M. 1999. Flesh availability and bone modifications in carcasses consumed by lions: palaoecological relevance in hominid foraging patterns. *Palaeogeography, Palaeoclimatology, Palaeoecology* **149**: 373-388.

Domínguez-Rodrigo M, Pickering T, Semaw S, Rogers MJ. 2005. Cutmarked bones from Pliocene archaeological sites at Gona, Afar, Ethiopia: implications for the function of the world's oldest stone tools. *Journal of Human Evolution* **48**: 109-121.

Domínguez-Rodrigo M, Barba R., Egeland CP. 2007. *Deconstructing Olduvai*: *A Taphonomic Study of the Bed I Sites*. Springer: Netherlands.

Domínguez-Rodrigo M, Yraveda J, Organista E, Gidna A, Fourvel JB, Baquedano E. 2015. A new methodological approach to the taphonomic study of paleontological and archaeological faunal assemblages: a preliminary case study from Olduvai Gorge (Tanzania). *Journal of Archaeological Science* **59**: 35-53.

Egeland CP. 2003. Carcass processing and cutmark creation: An experimental approach. *Plains Anthropologist* **48**: 38-51.

Egeland CP, Pickering TR, Domínguez-Rodrigo M, Brain CK. Disentangling Early Stone Age palimpsests: determining the functional independence of hominid- and carnivore-derived portions of archaeofaunas. *Journal of Human Evolution* **47**: 343-357.

Egeland CP, Kristen RW, Christopher MN. 2014. Experimental determinations of cut mark orientation and the reconstruction of prehistoric processing behaviour. *Journal of Archaeological Science* **49**: 126-133.

Faith JT. 2007. Sources of variation in carnivore tooth-mark frequencies in a modern spotted hyena (Crocuta crocuta) den assemblage, Amboseli Park, Kenya. *Journal of Archaeological Science* 34: 1601-1609.

Ferraro JV, Plummer TW, Pobiner BL, Oliver JS, Bishop LC, Braun DR, Ditchfield PW, Seaman III JW, Binetti KM, Seaman JR JW, Hertel F, Potts R. 2013. Earliest archaeological evidence of persistent carnivory. *PLoS One* doi: 10.1371/journal.pone.0062174

Frison LC, Todd LC. 1986. *The Colby mammoth site: taphonomy and archaeology of a Clovis Kill in Northern Wyoming*. University of New Mexico Press: Albuquerque.

Greenfield HJ. 2006. Slicing cut marks on animal bones: diagnostics for identifying stone tool type and raw material. *Journal of Field Archaeology* **31**: 147-163.

Harris JM, Cerling TE. 2002. Dietary adaptations of extant and Neogene African suids. *Journal of Zoology* 256: 45-54.

Haynes G. 1993. *Mammoths, mastodons, and elephants: biology, behavior and the fossil record*. Cambridge University Press: Cambridge.

Haynes G, Krasinski KE. 2010. Taphonomic fieldwork in Southern Africa and its application in studies of the earliest peopling of North America. *Journal of Taphonomy* **8**: 181-202.

Knauth LP. 1994. Petrogenesis of chert. in: Reviews in Mineralogy, Vol.29 Silica - Physical behavior, geochemistry and materials applications. Mineralogical Society of America, Washington, D.C.

Lyman RL. 1995. A study of Variation in the Prehistoric Processing of Large Artiodactyls. In *Ancient Peoples and Landscapes* Johnson E (ed.). Museum of Texas Tech University: Lubbock; 233-253.

Lupo KD, O'Connell JF. 2002. Cut and tooth mark distributions on large animal bones: Ethnoarchaeological data from the Hazda and their implications for the current ideas about early hominin carnivory. *Journal of Archaeological Science* **29**: 85-109.

Lupo KD. 2012. On early Hominin meat eating and carcass acquisition strategies: Still relevant after all these years? In *Stone Tools and Fossil Bones* Domínguez-Rodrigo M (ed.). Cambridge University Press: New York; 115-151.

Maté-González MA, Yravedra J, Martín-Perea DM, Palomeque-González J, San-Juan-Blazquez M, Estaca-Gómez V, Uribelarrea D, Álvarez-Alonso D, Cuartero F, González-Aguilera D, Domínguez-Rodrigo M. 2017. Flint and quartzite: distinguishing raw material through cut marks. *Archaeometry* http://dx.doi.org/10.1111/arcm.12327.

McPherron SP, Alemseged Z, Marean CW, Wynn JG, Reed D, et al. 2010. Evidence for stone-tool-assisted consumption of animal tissues before 3.39 million years ago at Dikika, Ethiopia. *Nature* **466**: 857–860. DOI:10.1038/nature09248.

Merritt SR. 2016. Cut mark cluster geometry and equifinality in replicated Early Stone Age butchery. *International Journal of Osteoarchaeology* **26**: 585-598.

Merritt SR. 2017. Investigating hominin carnivory in the Okote Member of Koobi Fora, Kenya with an actualistic model of carcass consumption and traces of butchery on the elbow. *Journal of Human Evolution* **112**: 105-133.

Milo RG. 1998. Evidence for human predation at Klasies River Mouth, South Africa, and its implications for the behavior of early modern humans. *Journal of Archaeological Science* **25**: 99-133.

Padilla M. 2008. Transmisión cultural y procesos de aprendizaje de carnicería: un estudio experimental comparando expertos y novicios en el descarnado y desarticulación. Available: ARQUEOWEB 9: http://www.ucm.es/info/arqueoweb/numero9_2/conjunto9_2.htm.

Pante MC, Blumenschine RJ, Capaldo SD, Scott RS. 2012. Validation of bone surface modification models for inferring fossil hominin and carnivore feeding interactions, with reapplication to FLK 22, Olduvai Gorge, Tanzania. *Journal of Human Evolution* **63**: 395-407.

Pobiner B. 2007. *Hominin-Carnivore Interactions: Evidence from Modern Carnivore bone Modification and early Pleistocene Archaeofaunas (Koobi Fora, Kenya; Olduvai Gorge, Tanzania).* New Brunswick: New Jersey.

Pobiner BL. 2015. New actualistic data in the ecology and energetics of hominin scavenging opportunities. *Journal of Human Evolution* **80**: 1-16.

Pobiner BL, Rogers MJ, Monahan CM, Harris JWK. 2008. New Evidence for Hominin carcass processing strategies at 1.5Ma, Koobi Fora, Kenya. *Journal of Human Evolution* **55**: 103-130.

Pobiner BL, Braun DR. 2005a. Applying actualism: considerations for future research. *Journal of Taphonomy* **3**: 57-65.

Pobiner BL, Braun DR. 2005b. Strengthening the Inferential link between cutmark frequency data and Oldowan Hominid behaviour: Results from modern Processing experiments. *Journal of Taphonomy* **3**: 107-119.

Potts R, Shipman P. 1981. Cut marks made by stone tools on bones from Olduvai Gorge, Tanzania. *Nature* **291**: 577-580.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Selvaggio MM. 1998. Evidence for a Three Stage Sequence of Hominid and Carnivore Involvement with long bones at FLK Zinjanthropus, Olduvai Gorge, Tanzania. *Journal of Archaeological Science* **25**: 191-202.

Selvaggio, MM. 1994. Carnivore tooth marks and stone tool butchery marks on scavenged bones: archaeological implications. *Journal of Human Evolution* **28**: 215-228.

Soulier M-C, Morin E. 2016. Cutmark data and their implications for the planning depth of Late Pleistocene societies. *Journal of Human Evolution* **97**: 37-57.

Soulier M-C, Costamagno S. 2017. Let the cutmarks speak! Experimental butchery to reconstruct carcass processing. *Journal of Archaeological Science: Reports* **11**: 782-802.

Speth JD. 1989. Early hominid hunting and scavenging: the role of meat as an energy source. *Journal of Human Evolution* **18**: 329-343.

Stiner MC, Gopher A, Barkai R. 2011. Hearth-side socioeconomics, hunting and paleoecology during the late Lower Paleolithic at Qesem Cave, Israel. *Journal of Human Evolution* **60**: 213-233.

Stout D, Quade J, Semaw S, Rogers MJ, Levin NE. 2005. Raw material selectivity of the earliest stone toolmakers at Gona, Afar, Ethiopia. *Journal of Human Evolution* **48**: 365-380.

The University of Auckland. 2005. Geology rocks & minerals website entry on argillite: https://flexiblelearning.auckland.ac.nz/rocks_minerals/rocks/argillite.html. Accessed December 21, 2017.

Thompson JC, McPherron SP, Bobe R, Reed D, Barr WA, Wynn JG, Marean CW, Geraads D, Alemseged Z. 2015 Taphonomy of fossils from the hominin-bearing deposits at Dikika, Ethiopia. *Journal of Human Evolution* **86**: 112-135.

Ungar PS. 2007. *The Evolution of the Human Diet: The Known, the Unknown and the Unknowable*. Oxford University Press: New York.

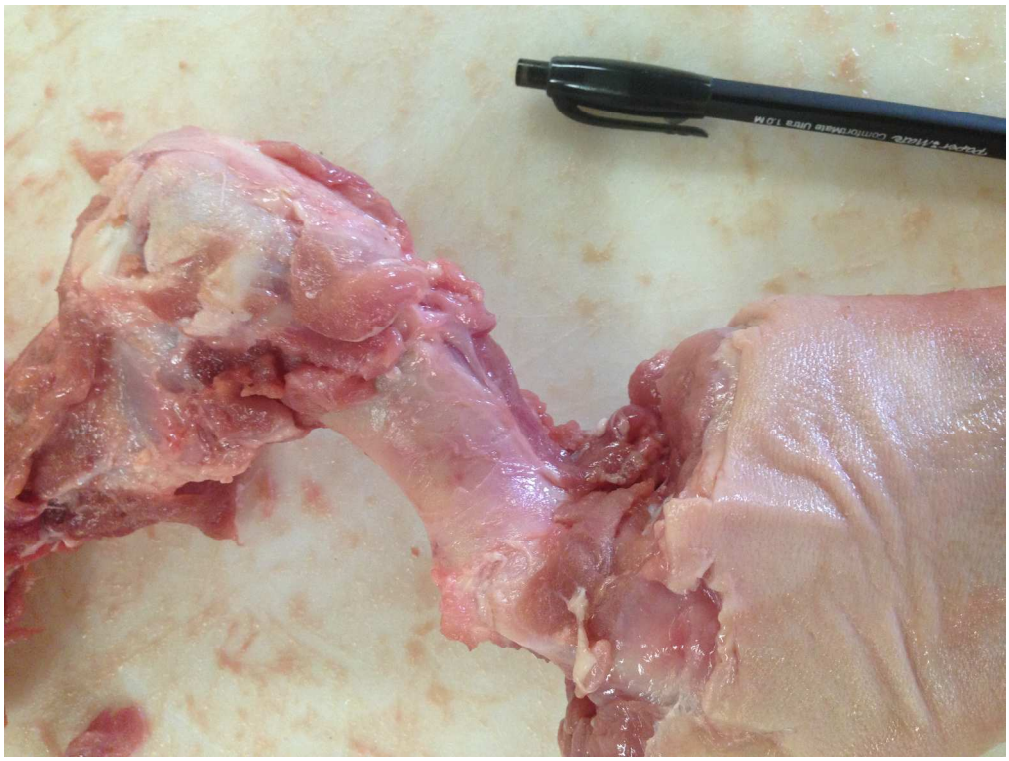

Figure 1. A close up view of one of the limbs post-butchery: the right forelimb butchered by the novice, showing the level of defleshing on the humerus.

1151x863mm (72 x 72 DPI)

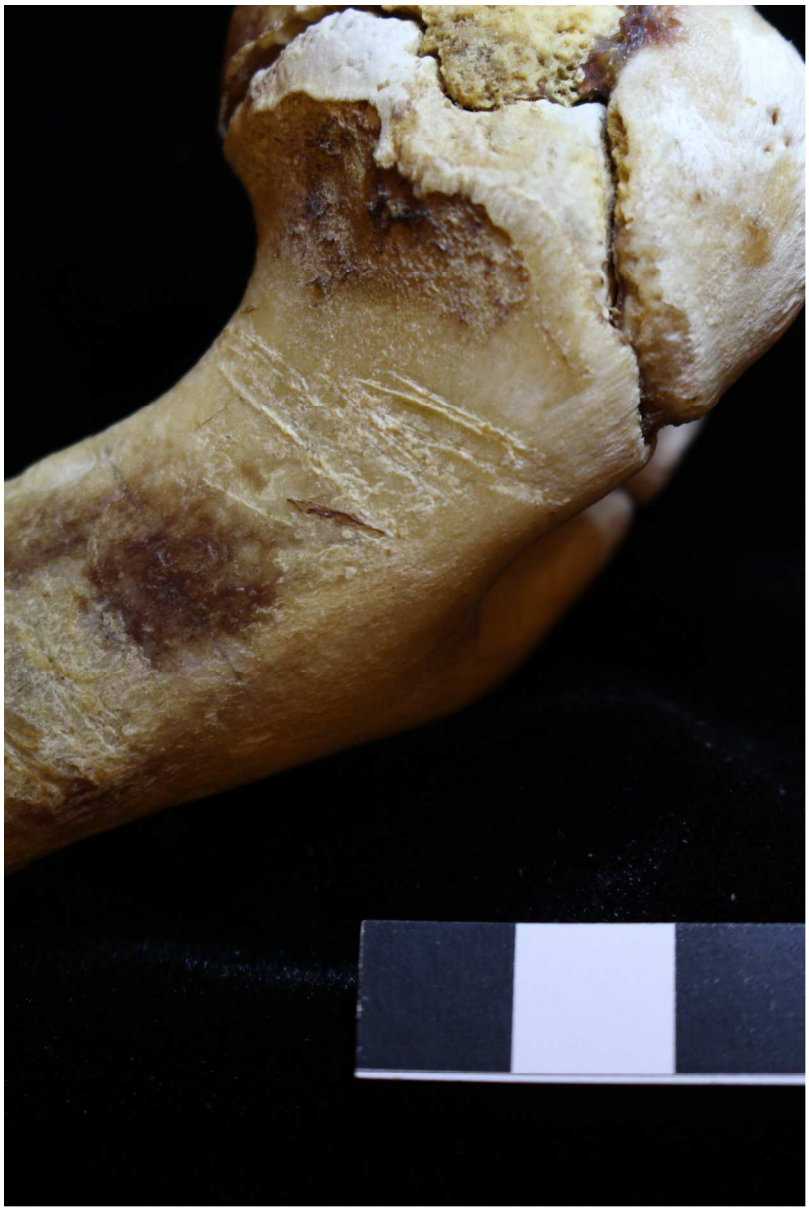

Figure 2. Cut marks on proximal humerus made by novice butcher, showing the typical appearance of a cluster of cut marks. Scale bar is 1cm blocks.

1219x1828mm (72 x 72 DPI)

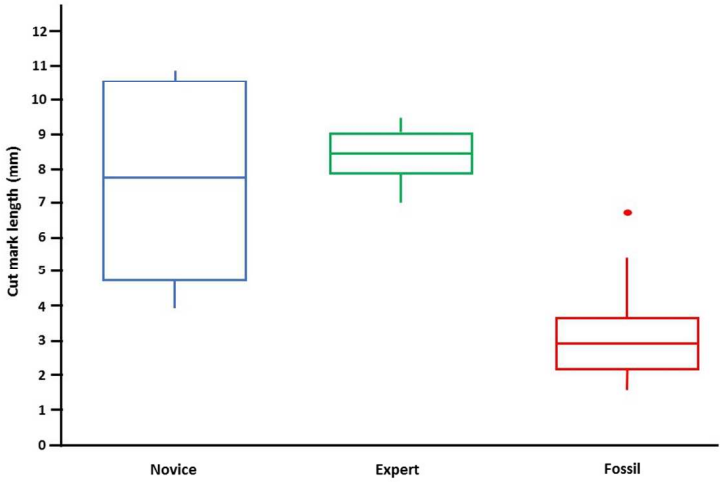

Figure 3. Box plots of length measurements of novice (left), expert (center), and fossil (right) cut marks.

338x190mm (96 x 96 DPI)

Table 1. Predictions for cut mark variables.

	Cut mark count	**Average cut mark length**	**Number of tool strokes**
Pre-butchery flesh quantity			
Fleshed	Lower	Longer	Lower
Defleshed	Higher	Shorter	Higher
Butcher expertise			
Expert	Lower	Shorter	Lower
Novice	Higher	Longer	Higher
Number of tool strokes	Positive correlation		

Table 2. Experimental cut mark summary data.

Experiment Code	Limb	Skeletal Element	Cut Mark Count (Skeletal Element)	Average Cut Mark Length (Skeletal Element)	Average Cut Mark Length (Entire Limb)	Tool Stroke Number (Entire Limb)	Butchery Time (Entire Limb)
ExDefl	Right Forelimb	humerus	12	9.54	9.54	850	10:12
		radius	0	0			
		ulna	0	0			
ExDefl	Left Hindlimb	femur	5	11.24	8.14	522	6:40
		tibia	6	8.3			
		fibula	3	2.67			
NovDefl	Right Hindlimb	femur	0	0	4.02	940	19:38
		tibia	2	5.25			
		fibula	3	3.21			
NovDefl	Left Forelimb	humerus	18	10.48	10.48	676	14:30
		radius	0	0			
		ulna	0	0			
ExFl	Left Forelimb	humerus	7	7.53	7.02	650	8:17
		radius	0	0			
		ulna	1	3.46			
ExFl	Right Hindlimb	femur	13	7.1	8.81	775	9:14
		tibia	1	11.82			
		fibula	2	10.15			
NovFl	Right Forelimb	humerus	18	4.96	5.05	636	13:05
		radius	0	0			
		ulna	1	6.91			
NovFl	Left Hindlimb	femur	1	18.41	10.78	935	16:56
		tibia	6	7.44			
		fibula	6	12.86			

Abbreviations: Ex=Expert; Nov=Novice; Defl=Defleshed; Fl=fleshed
Cut mark length reported in millimeters
Butchery time reported in minutes:seconds

Table 3. Fossil cut mark data.

Fossil site	Catalog Number	Taxon	Animal Size Class	Skeletal Element	CM #1 Length	CM #2 Length	CM #3 Length	CM #4 Length	CM #5 Length	CM #6 Length	CM #7 Length	CM #8 Length	CM #9 Length	CM #10 Length	CM #11 Length	CM #12 Length
FwJj14A	154+173	Mammal	3B/4	radius	4.29	5.82										
FwJj14A	418	Mammal	3	humerus	6.73											
FwJj14A	1016-97	Bovidae	3	radius	2.96	1.46	3.11	2.81	2.12	2.65	1.51	3.09	1.50	2.13	2.08	1.92
FwJj14A	1019-97	Bovidae	3A	femur	5.26	4.39	12.41	3.36	4.10	4.75	3.23	6.50				
FwJj14A	1022-97	Mammal	3	humerus	4.00	4.30	2.96	2.46								
FwJj14A	1024-97	Bovidae	3	tibia	5.00	5.78	4.41									
FwJj14A	1056	Mammal	2/3A	femur	5.12											
FwJj14A	1107	Bovidae	3	tibia	2.32											
FwJj14A	1108	Bovidae	3A	tibia	2.40	5.39	3.05	2.30	1.74	2.84	2.76					
FwJj14A	1122+1125	Bovidae	3	tibia	4.67	1.48	1.84	2.08	1.58	2.13						
FwJj14A	1130	Bovidae	3	tibia	1.12	1.35	1.92	2.21	4.06	1.92						
FwJj14A	1131	Bovidae	3	tibia	1.59	1.56	1.61	1.51	2.62							
FwJj14B	3090	Bovidae	3B/4	humerus	4.49	4.54	2.58	2.40	2.49							
FwJj14B	3096	Bovidae	3	tibia	2.96	4.29	2.01	2.76	4.16	2.96	1.52					
FwJj14B	5230	Bovidae	2	ulna	2.99	1.36										
FwJj14B	6021	Bovidae	2	radius	4.37	4.06										
FwJj14B	6040	Mammal	3	femur	5.31	2.17	2.14	2.22								
FwJj14B	6090a	Bovidae	3	radius	1.17	0.84	1.20	2.39	1.95	1.86	2.29					
GaJi14A	3	Bovidae	2	tibia	1.44	1.54	2.00	2.47	2.99	2.69						
GaJi14A	108	Mammal	2	fibula	1.78	1.70	1.93	1.16	1.50							
GaJi14A	1019	Mammal	3/4	tibia	2.30	3.10	1.54	1.73								
GaJi14A	1030	Bovidae	2	radius	2.51	1.51	2.76	2.07	1.21	2.32						
GaJi14A	1042	Mammal	3	femur	4.55	3.62	2.54	5.89	4.93	2.05	6.54					
GaJi14A	1052	Bovidae	3	tibia	3.46	2.76										
GaJi14A	1055	Bovidae	3	humerus	4.29	2.10	2.70	3.56	3.16	2.83	3.12					
GaJi14A	1058	Mammal	3	femur	3.74	4.46	2.02	1.94								
GaJi14A	1061	Mammal	3	tibia	1.38	2.01	1.55	1.81	1.49	3.03	1.97					
GaJi14A	1064	Bovidae	3A	ulna	3.28	2.96	2.65									

Cut mark (CM) length reported in millimeters

Size 2 = 50-250 lbs; Size 3A = 250-500 lbs; Size 3B = 500-750 lbs; Size 4 = 750-2000 lbs

Table 4. Results for cut mark variables.

	Cut mark count	**Average cut mark length**	**Number of tool strokes**
Pre-butchery flesh quantity			
Fleshed	Lower (n=56)	**Longer (9.06)**	Lower (n=2996)
Defleshed	Higher (n=49)	**Shorter (7.24)**	Higher (n=2988)
Butcher expertise			
Expert	**Lower (n=50)**	**Shorter (7.97)**	**Lower (n=2797)**
Novice	**Higher (n=55)**	**Longer (8.69)**	**Higher (n=3187)**
Number of tool strokes	Positive correlation		

Bold text indicates results that match expected predictions in Table 1

Table 5. Mann-Whitney U-Test results.

	Test-Statistic	P-Value	95% Confidence Interval	Difference in Median
Amount of Flesh * Average Cut Mark Length	8	1.000	-6.76, 5.43	0.215
Amount of Flesh * Number of Cut Marks	6	0.686	-14, 10	-1.5
Amount of Flesh * Number of Tool Strokes	9	0.886	-413, 304	15.5
Butcher Experience * Average Cut Mark Length	8	1.000	-3.76, 5.52	0.515
Butcher Experience * Number of Cut Marks	6	0.686	-11, 11	-2.5
Butcher Experience * Number of Tool Strokes	5	0.486	-418, 214	-102

Table 6. Results of Tukey's HSD test comparing cut mark frequency means across skeletal elements.

Skeletal Elements	Difference	Lower	Upper	p-adjusted
Fibula-Femur	-2.833	-12.499	6.832	0.878
Humerus-Femur	7.417	-2.249	17.082	0.168
Tibia-Femur	-2.583	-12.249	7.082	0.909
Ulna-Femur	-5.333	-16.886	6.219	0.598
Humerus-Fibula	10.250	1.301	19.199	**0.023**
Tibia-Fibula	0.250	-8.699	9.199	1.000
Ulna-Fibula	-2.500	-13.460	8.460	0.946
Tibia-Humerus	-10.000	-18.949	-1.051	**0.026**
Ulna-Humerus	-12.750	-23.710	-1.790	**0.020**
Ulna-Tibia	-2.750	-13.710	8.210	0.926

Bold values indicate statistical significance